Null cosmic strings and space-time content

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based on **PRD 105 083510 (2022)**

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Motivation

Cosmic strings - hypothetical 1D extended objects (massive and massless)

Possible mechanisms of origin

- Phase transitions in the early universe (Kibble mechanism for massive strings)
- Physics on the Planck scale (massless limit in string theory)

Numerous studies have been carried out on massive strings, since they open up the possibility to study GUT physics or Planckian physics

Massless strings are little studied, were first considered by A. Schild (1977)

Key Features and Effects of Null Strings

Physical effects (**PRD 96 (2017) 104005**, **PRD 98 (2018) 123531**)

- ✸ gravitational lensing (changing the trajectory of bodies)
- ✸ influence on the anisotropy of relic radiation

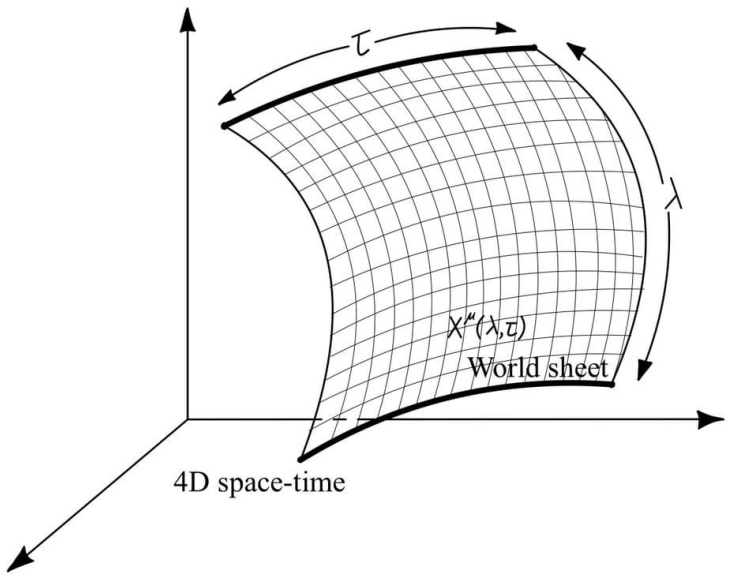
Key differences
between null (massless) strings and massive ones:

- ★ The world surface is a degenerate 2D surface
- ★ Described by an optical
  equation analogous to the Sachs equation
- ★ World surfaces of null strings can have caustics

Description of massless strings

World surface – null 2D surface $x^\mu = x^\mu(\lambda, \tau)$
$l^\mu = x^\mu_{,\lambda}$ - velocity vector
$\eta^\mu = x^\mu_{,\tau}$ - connecting vector

$h_{ab} = g^{\mu\nu} x^\mu_a x^\nu_b \Longrightarrow \det h = 0$



Schild equations

$l^2 = 0, \quad (l \cdot \eta) = 0, \quad \eta^2 > 0, \quad \nabla_l l \sim l$

Tetrade: l, n, p, q
$p = \eta/|\eta|$, n is null, $(n \cdot l) = -2$
q is unite, spacelike

Optical scalars

$\theta = \partial_\lambda \ln \eta$ - expansion (curvature)
$\kappa = (q \cdot \nabla_p l)$ - rotation (torsion)

$$Z = \theta + i\kappa$$

Optical equation and SET of null string

An analogue of the optical Sachs equation for null geodesic congruences **PRD 103 (2021) 123526**

$$\partial_\lambda Z + Z^2 = -\Psi_0 - \Phi_{00}$$

$$\Psi_0 = -C_{mlml} \qquad \Phi_{00} = -\frac{1}{2}R_{ll} \quad m^\mu = \frac{1}{\sqrt{2}}\left(p^\mu + iq^\mu\right)$$

Stress–energy tensor is introduced in **PRD 105 (2022) 083510**

$$T^{\mu\nu}(x) = \int d\lambda d\tau \; \frac{1}{\sqrt{-g}} \bar{\mu}(\lambda,\tau) \; \delta^4(x-\bar{x}) \; l^\mu(\bar{x}) l^\nu(\bar{x})$$

$\bar{\mu}(\lambda,\tau)$ - string energy per unit length

$$\nabla_\mu T^{\mu\nu}(x) = 0 \Longrightarrow \partial_\lambda \bar{\mu} + \theta\bar{\mu} = 0$$

How do μ and Z depend on the matter distribution?

Asymptotically flat space

Null strings propagate towards $\mathcal{J}^+$

BS formalism is the study of energy flows in the form of radiation (EM, gravitational) at light infinity $\mathcal{J}^{\pm}$ (1962г.)

BS metric

$$ds^2 = -\frac{V}{r}e^{2\beta}du^2 - 2e^{2\beta}dudr + r^2 h_{AB}(dx^A - U^A du)(dx^B - U^B du)$$

According to the peeling theorem (**arXiv: 0906.2155 [gr-qc]**)

$$\Psi_0\big|_{\lambda\to\infty} = \psi_0^0(\tau)\lambda^{-5} + O(\lambda^{-6})$$

$$\Phi_{00}\big|_{\lambda\to\infty} = \phi_{00}^0(\tau)\lambda^{-6} + O(\lambda^{-7})$$

Asymptotic behavior of an optical scalar Z and string energy μ

$$Z = \frac{1}{\lambda} - \frac{z}{\lambda^2} + \frac{z^2}{\lambda^3} + \frac{\frac{1}{2}\psi_0^0 - z^3}{\lambda^4} + O(\lambda^{-5})$$

$$\mu(\lambda,\tau) = \mu(\tau)\left[\frac{1}{\lambda} - \frac{\Re z}{\lambda^2} + \frac{\Re z^2 + (\Re z)^2}{2\lambda^3} + \frac{\Re\psi_0^0}{6\lambda^4} + O(\lambda^{-5})\right]$$

$$z(\tau) = z_0(\tau) + \frac{1}{2}\left(C_\oplus + iC_\otimes\right) + M$$

$\psi_0^0 \sim J, M, C$ – gravitational radiation (**PRD 105 (2022) 083510**)

$z_0(\tau)$ determined by the trajectory of the string in flat space

$C_\oplus, C_\otimes$ — gravitational wave polarization

J – angular momentum aspect affects θ and κ

M – mass aspect affects string expansion θ

C - gravitational radiation affects θ and κ

Conclusion

1. Optical scalars of the string world-sheet encode information about space-time content (mass and angular momentum aspects, background GW)
2. Space-time content affects local energy of a string segment (leading effect are from mass aspect and interaction of the string with GW)
3. Local energy of null strings determines physical effects caused by null strings (lensing effects, Kaiser-Stebbins effect, etc)
4. Null strings may carry a valuable information about the early stages of the Universe (an analogy with relic photons - CMB)

Thank you for your attention!